History of Endovascular Endosaccular Occlusion of Brain Aneurysms: 1965-1990

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Summary

A concise historical review of the endovascular, endosaccular treatment of intracranial aneurysms is reported. The transition from detachable balloons to detachable coils is described. The development of microcatheters for intracranial endovascular navigation is also reported.

Introduction

This paper concisely describes the history of endovascular intracranial navigation and the history of the endovascular endosaccular treatment of brain aneurysms, from detachable balloons to detachable coils. It is mainly aimed at the second generation of endovascular neurosurgeons: those who did not personally witness and live through the "endovascular revolution".

Endovascular Navigation

The idea of using blood vessels as natural conduits to navigate into vascular lesions of the brain stimulated the development of various delivery systems (i.e. microcatheters). The tortuosity, narrowness and delicacy of intracranial arteries, as well as the presence of the carotid siphon, are obstacles to intracranial navigation. Pioneer investigators have, in the past, directed their efforts to overcome the challenge of safely catheterizing brain arteries.

The history of endovascular intracranial navigation starts with the work of two neurosurgeons of the Georgetown University Hospital in Washington, Luessenhop and Velasquez, who reported the first catheterization of brain vessels in 1964 [16]. They used a glass chamber, surgically connected to the external carotid artery, to deliver a length of silastic tubing into the internal carotid artery and thereby into brain arteries (figure 1). In one instance, the distal tip of the catheter was inflated, like a balloon, to temporarily occlude the neck of a large posterior communicating artery aneurysm. They stated that "intraluminal manipulation of the intracranial arteries about the circle of Willis is possible technically and is tolerated by these arteries". Furthermore, they prophetically wrote: "catheterization as well as embolization of the intracranial arteries may have therapeutic usefulness, particularly in the treatment of aneurysms and arteriovenous malformations". At that time, however, catheterization of cerebral arteries was generally considered exceedingly difficult and hazardous.

The POD Microcatheter

In the 1960s, developments in microcatheter technology were pioneered by Frei and colleagues from the Department of Electronics at the Institute of Science in Israel. In 1966 they published [6] a description of a novel microcatheter which they called a POD (Para-Operational Device). This catheter was designed for superselective catheterization with a minimum of vessel trauma. The proximal portion was made of polyethylene and the distal portion of soft silicone rubber. The distal section measured only 1.3 mm in outer diameter and was 7 cm in length. Embedded in the tip of the silicone tubing was a micromagnet which measured 1 mm in diameter. External magnetic fields, both continuous and alternating, could be applied to pull the micromagnet-tipped microcatheter (by the continuous field) and to cause it to vibrate (by the alternating magnetic field). The effect was to induce the catheter to "swim" within the vessels by reducing friction between the catheter tip and the inner vessel wall. They also introduced the concepts of a guide catheter in the extracranial vasculature to support the POD, and a side-arm adapter (which they called the "plastic T") to introduce the microcatheter and to inject saline to flush the guide catheter. Today, 40 years later, we are still using tools developed for this system. Frei and colleagues prophetically considered electrothrombosis a possible therapy for intracranial aneurysms and stated that "possibly the most dramatic application of the POD catheter is for the electrical obliteration of cerebral aneurysms and the selective treatment of other cerebral anomalies". They successfully tested the magnetically guided catheter in vitro using a glass model of the carotid artery siphon and were able to select and catheterize model aneurysms.

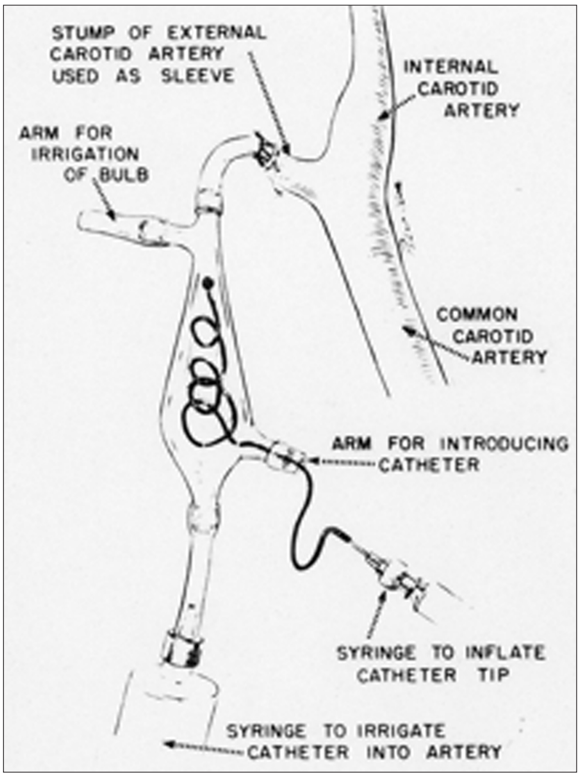

Figure 1 Schematic illustration showing the report on the first catheterization of intracranial arteries. Luessenhop AJ, Velasquez AC: Observations on the tolerance of the intracranial arteries to catheterization. J Neurosurg 21:85-91, 1964.

The concept of magnetic guidance became popular amongst investigators during the 1960s. In 1967, Yodh and colleagues [20] from the Neurosurgery Service of Massachusetts General Hospital constructed a "magnet system for use in such areas as the treatment of intracranial aneurysms and other vascular malformations". Applying the same principles as Frei et Al (vide supra), the system used a large (5 kW) movable external electromagnet to propel and guide a 1.3-mm permanent magnet incorporated in the tip of a silastic microcatheter. Six different tips were made in detachable and non-detachable versions. The detachable tip included a cavity at the rear of the micromagnet filled with paraffin wax in which a minute heating coil was embedded. Constructed of ten turns of 0.5-mm copper wire, the coil was connected to an external source of electricity via copper leads in the catheter and when a current of 400 mA was applied heating of the coil caused the wax to melt and the tip to detach. One non-detachable version was constructed with a central lumen in the tip magnet so that embolic materials could be injected. They predicted three uses for the catheters: 1) to block the feeding vessels of certain intracranial vascular malformations by implanting the detachable tip or by injecting congealable plastic, 2) to thrombose certain intracranial aneurysms by endosaccular injection of a congealable plastic, or by detaching a magnetic tip inside the sac and then injecting through the catheter iron particles which would adhere to the detachable tip, and 3) for superselective intra-arterial injection of chemotherapeutic drugs in high concentrations for the treatment of glioma. Some of these concepts are still in use 40 years later.

In 1969, the first report of magnetically guided intracranial navigation in man was made by Driller et Al [4]. They utilized a POD catheter, introduced by percutaneous carotid puncture, to perform the first ever catheterization of the middle cerebral artery of a patient.

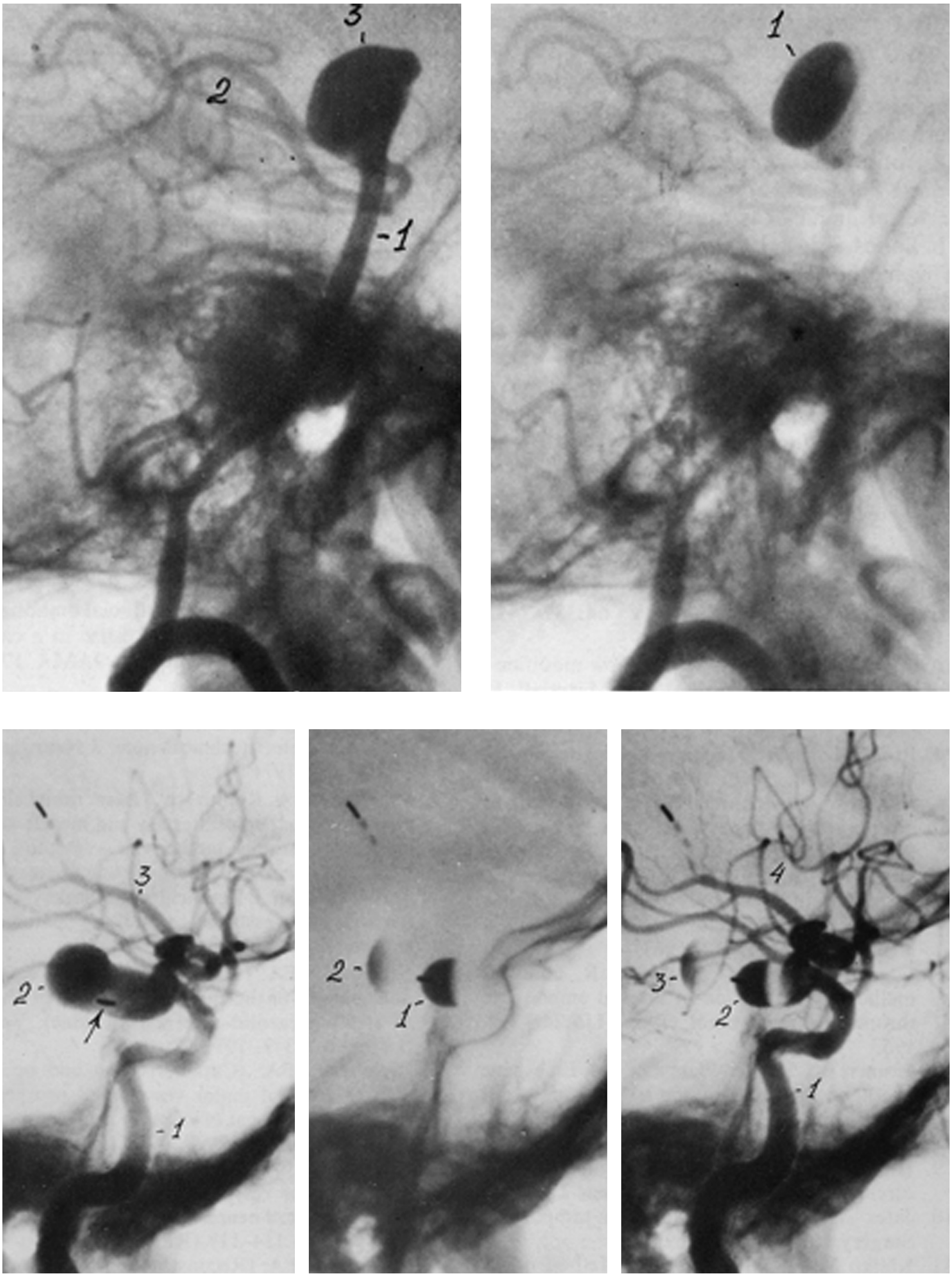

Figure 2 Illustration showing the first report on the endosaccular occlusion of intracranial aneurysms with detachable balloons. Serbinenko FA: Balloon catheterization and occlusion of major cerebral vessels. J Neurosurg 41: 125-145, 1974.

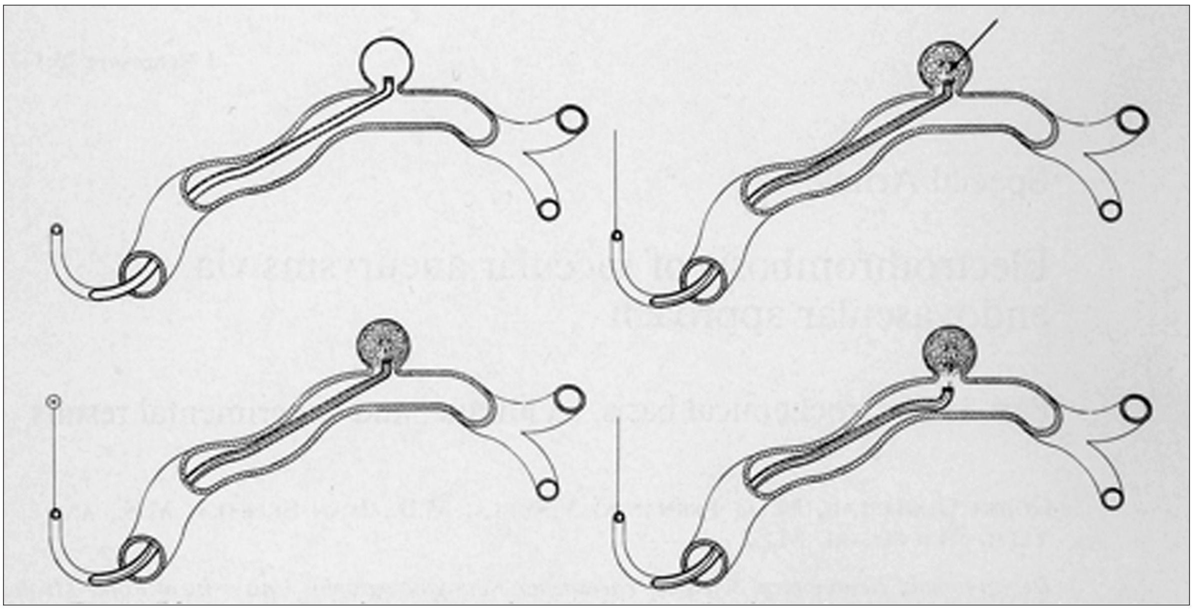

Figure 3 Schematic illustration showing the technique of endosaccular occlusion of aneurysms with detachable coils. Guglielmi G, Viñuela F, Sepetka I, Macellari V: Electrothrombosis of saccular aneurysms via endovascular approach. Part 1: electrochemical basis, technique and experimental results. Special article. J Neurosurg 75: 1-7, 1991.

In 1970, Montgomery et Al[17] described a modified version of POD which incorporated a small detachable balloon which could be inflated and detached. A rubber valve retained the solution used to inflate the balloon. This was the first report of a detachable balloon for endovascular use.

In 1973, Cares et Al[1], from the Neurosurgery Service of Massachusetts General Hospital, Boston and the Massachusetts Institute of Technology, introduced the concept of endosaccular balloon occlusion of aneurysms. They published details of experimental work on a magnetically guided intravascular microcatheter that could deliver iron microspheres, isobutyl-cyanoacrylate and detachable balloons for endovascular obliteration of aneurysms and arteriovenous malformations. The catheter, which was made of silicon, was flow-directed and the external magnetic field was utilized only to deflect its tip at critical arterial junctions. They developed a detachable balloon made of latex with a carbon steel cylinder in the collar used to mount the balloon on the catheter. To inflate and detach the balloon from the microcatheter, a solution containing 25% serum albumen was injected to fill the balloon and the carbon steel cylinder was heated by means of a remote (extracorporal) radiofrequency induction coil. When the temperature of the cylinder reached 55°C, the albumen coagulated and sealed the orifice of the balloon. Injection of an additional 0.1 cc of albumen solution expanded the delivery microcatheter and detached the balloon.

In 1974, one year later, Hilal et Al[12], from Columbia University, New York, reported on the clinical use of a slightly modified version of the POD microcatheter in 120 patients. They were able to perform percutaneous catheterization of vessels such as the basilar, middle cerebral and lenticulostriate arteries. They injected embolic substances, including acrylics, into arteriovenous malformations, performed intracranial intravascular electroencephalography and, in one patient, performed endovascular electrothrombosis of a basilar artery aneurysm.

In spite of some success in negotiating intracranial vessels, POD did not become popular and was later abandoned for new microcatheters which appeared on the horizon of endovascular neurosurgery.

The Tracker Microcatheter

In the mid-1970s Debrun, an interventional neuroradiologist, devised, tested and clinically applied[2] a coaxial microcatheter system with a detachable, tied-up, latex balloon at its tip. Due to its relative stiffness, however, the Debrun system could only reach the cavernous portion of the internal carotid artery. With this microcatheter, balloon endovascular treatment of direct carotid-cavernous fistulae (with preservation of the carotid artery) and giant intracavernous aneurysms (with sacrifice of the carotid artery) became the gold standard procedures.

In 1981 Hieshima, an interventional neuroradiologist, devised a thin (2.0-French), soft polyethylene microcatheter to be used with a detachable silastic balloon for the endovascular occlusion of intracranial aneurysms [10]. This system was utilized by several centers specialized in endovascular navigation for the treatment of brain aneurysms.

A fundamental milestone in the history of neuro-endovascular navigation was reached in the mid-1980s. Engelson, a biomechanical engineer working with a then small company (Target Therapeutics), had the idea of modifying and improving an existing microcatheter. He attached to the proximal polyethylene portion a short distal section which was softer than polyethylene but stiffer than the silicone tubing used in existing microcatheters: the variable stiffness "Tracker" microcatheter was born. He also devised a steerable microguidewire with a deformable tip to negotiate vascular bends, and engineered a small radiopaque marker at the tip of the microcatheter. By pushing the microcatheter over the microguidewire, the system was capable of entering brain vessels while remaining steerable [5,15]. The "Tracker" allowed intracranial navigation simply by pushing the catheter over the steerable guidewire. In 1985, Engelson started animal testing of his new microcatheter at the Interventional Neuroradiology Section of New York University. The Tracker microcatheter was first used in patients in 1986 in the external carotid artery and subsequently in intracranial vessels. It allowed intracranial navigation simply by pushing the microcatheter and for the first time the operator did not have to rely on an external force, i.e. external magnets, nor antegrade blood flow to perform distal superselective catheterization. A range of such microcatheters became available to the endovascular therapist, designed for endovascular navigation using a microguidewire. They were used to deliver balloons, coils and liquid agents. This "over the wire" microcatheter opened the door to the widespread

Figure 4 Angiogram showing a small-necked basilar apex aneurysm (lateral view). The aneurysm was selectively occluded with 2 platinum detachable GDC coils (total coil length: 65 cm). This procedure was performed in 1990.

Figure 5 This 6-year follow-up angiogram shows persistent complete occlusion of the aneurysm.

use of intracranial navigation with a safe, simple and efficient system. It also opened the door to possible direct catheterization of cerebral aneurysms (vide infra).

Detachable Balloons

In 1974 the field of endovascular neurosurgery was shaken by a report of Serbinenko, a neurosurgeon of the Burdenko Neurosurgical Institute in Moscow, who described the endovascular treatment of over 300 patients using detachable and non-detachable balloons [19]. It was the first report demonstrating the feasibility of temporary balloon occlusion of cerebral arteries, endovascular occlusion of direct carotid-cavernous fistulae with preservation of the parent artery, and endovascular endosaccular occlusion of brain aneurysms, preserving the parent artery (figure 2). This work had an exceptional influence on endovascular neurosurgeons, forming the clinical basis for future investigations.

The next decade saw the establishment of neuro-endovascular centers in which endosaccular balloon occlusion of cerebral aneurysms was practised. Debrun (London Ontario, Canada), Romodanov (Kiev, Ukraine), Hieshima (San Francisco, USA) and Moret (Paris, France), among other centers, applied Serbinenko's concepts and performed endosaccular balloon occlusion of intracranial aneurysms with preservation of the parent vessel. Their institutions attracted an entire generation of endovascular neurosurgeons.

In 1978 Debrun reported on the balloon occlusion of five intracavernous aneurysms with preservation of the parent artery [3]. However, the follow-up angiograms revealed reconstitution of the majority of aneurysms, in spite of the fact that he filled the latex balloons with silicone.

In 1982 Romodanov [18] reported on the balloon occlusion of 120 aneurysms with a 73% rate of preservation of the parent vessel. As to the limits of balloon embolization he stated that the endovascular operation was contraindicated in small aneurysms, aneurysms with a wide neck, acute phase post subarachnoid hemorrhage, and in the presence of severe vasospasm since the mortality amongst such patients was 22%.

In 1990 Higashida [11] reported on a series of 84 inoperable aneurysms of the anterior and posterior circulation: an 18% mortality rate and an 11% morbidity rate directly related to the balloon embolization procedure was observed.

Balloons did not adopt the shape of the aneurysm and, therefore, they produced an "angioplasty" of the aneurysmal cavity. Balloons, in other words, forced the aneurysm to adapt to the shape of the balloon. This entailed a high incidence of aneurysm rupture. Furthermore, intrasaccular balloons were filled with hydroxyethylmethacrylate (HEMA), a solidifying agent utilized to prevent balloon deflation. HEMA filled balloons are stiff and more likely to transmit the energy of the systolic pulse to the walls of the aneurysm. The high rates of morbidity and mortality following balloon occlusion were not acceptable to most neurosurgeons all over the world. Due to the high incidence of severe immediate complications, delayed rupture of the aneurysm and recanalization, balloon embolization did not become popular, failed to attain widespread utilization, and was adopted only in small clinical series. Balloon embolization of surgical brain aneurysms seemed attractive only to ingenuous and candid observers. The price of anecdotal impressive anatomical results was the unacceptable death of many patients. Doctors who propagandized this technique for surgical aneurysms tainted the reputation of interventional neuroradiology.

Detachable Coils

The substantial failure of balloon embolization prompted investigators to find a less traumatic embolic agent that could gently adopt the shape of the aneurysm. In 1988 Hilal (Columbia University, New York) reported the first use of short pushable coils for endosaccular packing of intracranial aneurysms [14,15]. With these relatively stiff coils, however, dense aneurysm packing could not be achieved. Furthermore, as these coils were non retrievable, an unwanted deposit in the parent artery was highly probable.

Considering the inherent dangerousness and uncontrollability of balloons, in 1989 Guglielmi, an endovascular neurosurgeon, devised very soft, controllable, retrievable, detachable platinum coils for a safer and effective treatment of brain aneurysms. The history of these detachable coils started in 1989 at the University of California (U.C.L.A.) with experimental research which eventually led to the development of what is still called the GDC system [7]. This study followed the classic steps of applied research: in vitro demonstration, in vivo animal experimentation, and clinical application [8]. Persons like Sepetka (engineer at Target Therapeutics), Viñuela (interventional neuroradiologist at U.C.L.A.), and Engelson (engineer at Target Therapeutics) played important roles in the construction, application and production of the "new" detachable coils.

This new technique was developed to overcome the limits of balloon embolization (vide supra). Aneurysms could be treated in the acute phase of subarachnoid hemorrhage and in the presence of vasospasm. The embolic material is a soft, controllable, detachable, platinum coil, two to 30 centimeters in length, soldered to a stainless steel delivery wire. The tip of an "over the wire" microcatheter (vide supra) is positioned in the aneurysm. The detachable coil is then advanced through the microcatheter and deposited in the aneurysm. If the position is unsatisfactory (i.e. if there is a deposit in the parent artery), the coil can be retrieved and redeployed at will. A positive direct electrical current is then applied to the proximal end of the delivery wire. The current electrolytically dissolves the delivery wire just proximal to the platinum coil, detaching the coil within the aneurysm (figure 3). Numerous coils may be deposited in the aneurysm. The aneurysm is slowly and gently filled with coils until it is completely and tightly "packed" (figures 4,5). The detachable coils adapt themselves to the shape of the aneurysm, and they produce much less deforming pressure upon the fragile walls of the aneurysm than did an inflated balloon.

On March 6, 1990 the GDC coil was utilized for the first time in the clinical setting: at U.C.L.A., two GDC coils were successfully delivered and electrolytically detached in a cavernous carotid aneurysm, preserving the parent artery [9].

To date (March 2007), 250,000 patients have been treated with the detachable coil technique worldwide. At the present time (March 2007), about 50,000 patients a year are treated all over the world via the endovascular approach using detachable coils.

Conclusions

The technology produced soft steerable microcatheters that allowed safe and less traumatic intra-arterial access into an aneurysm. This capacity of intracranial, intra-arterial navigation opened the door to new treatment strategies. This type of access used the arteries as natural channels to reach the sac of the aneurysm, without the need for craniotomy.

Coil technology developed in parallel: it allowed widespread use of the endovascular approach in the treatment of aneurysms. Significant results were achieved in aneurysms with a small neck (equal to or less than 4 millimeters). Less satisfactory results were achieved in wide-necked aneurysms. At the present time, this subset of aneurysms appears to be better treated with the aid of endovascular stents, when possible.

It is hoped that the concepts described in this concise historical review may help future investigators to find improved therapeutic strategies for the endovascular treatment of brain aneurysms.

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